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CONTRIBUTIONS FROM THE JEFFERSON PHYSICAL LABORATORY, HARVARD UNIVERSITY.

THE SPECTRUM OF A CARBON COMPOUND IN THE REGION OF EXTREMELY SHORT WAVE-LENGTHS.

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In the region of extremely short wave-lengths discovered by Schumann the spectra of two gases only are easily obtained; the one is due to hydrogen, the other to some compound of carbon.[1] The hydrogen spectrum consists of a great number of fine lines extending from λ 1675 to λ 1030; the wave-lengths of the most prominent of these lines have been determined.[2] The carbon spectrum consists of a considerable number of bands extending from the less refrangible end of the Schumann region to the neighborhood of λ 1300. The purpose of the present investigation was to measure the position of these bands.

The results are chiefly valuable because the bands in question fill the gap between λ 1854 and λ 1675 and form convenient standards of wave-length in a region which up to this time has lacked points of reference.

The appearance of the spectrum is shown in Plate VIII, Volume 13, of the Memoirs of this Academy. It is marked "Air." The bands are most intense in the less refrangible region, but they are all of the same general type with heads directed toward the region of shorter wave-length. The strongest bands are evidently double. The system, at least throughout its less refrangible part, forms a continuation of the "Fourth group" as described by Deslandres in his paper, "Spectre de bandes ultra-violet des composés hydrogénés et oxygénés du carbone."[3] The spectrum under investigation is thus related to the series of bright bands in the visible and ultra-violet attributed to carbon monoxide and often observed in ill-prepared vacuum tubes.

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[1] Smithsonian Contributions, 1903, **29**, No. 1413.

[2] Lyman, Memoirs of this Academy, 1906, **13**, 125.

[3] Comptes Rendus, 1888, **106**, 842.

It is only too easy to obtain the bands in the region of short wavelengths, for, to quote Schumann himself,[4] they are "the unwelcome attendants of all my spectra." In order to determine the cause of the phenomenon, however, experiments were made with both carbon monoxide and carbon dioxide and with a variety of conditions in the discharge tube. The results of these experiments may be stated as follows: Exactly the same bands are obtained when carbon monoxide is used as when carbon dioxide is employed, but in the former case the strength of the whole spectrum is considerably greater than in the latter. With increased current strength from a transformer, between five and twenty milliamperes the intensity of the bands increases in a uniform manner throughout the extent of the spectrum. When a spark gap is placed in series with the tube and a condenser is introduced in such a way as to produce a disruptive discharge, the spectrum at first weakens and then vanishes altogether. The effect is accompanied by a very marked decrease in pressure in the tube and by the formation of a dark deposit on the walls of the capillary. When precautions are taken to exclude the introduction of carbon monoxide or prevent its formation, the spectrum is greatly weakened if it does not vanish altogether.

These data go to confirm the results of Schumann, as they show that the spectrum is due to carbon monoxide. The occurrence of the bands when carbon dioxide is present may be explained by the fact that this gas is known to be transformed into carbon monoxide under the influence of light and the electric discharge.[5] The disappearance of the spectrum with the disruptive discharge is due to the destruction of the carbon monoxide. The oxygen set free by the reaction seems to combine with the electrodes, while the carbon is deposited. This property of a condenser discharge is useful, since it permits the spectroscopist to free his apparatus of an annoying impurity. The decrease in pressure which accompanies this reaction is often a striking and important phenomenon.

In making measurements in the region between λ 1880 and λ 2080 a concave grating of six foot radius with 15028 lines to the inch was employed. Schumann plates were used throughout the work. For the experiments in the region on the more refrangible side of λ 1880 the writer's vacuum spectroscope was employed[6] in the same manner as when the hydrogen spectrum was under investigation. An improvement in the discharge tube, however, has been introduced. The nature

[4] Loc. cit., p. 16.
[5] Herchefinkel, Comptes Rendus, 1909, **149**, 395.
[6] See note 2.

of the change will be understood by consulting the illustration on page 90 of volume 27 of The Astrophysical Journal. The brass collar A is no longer provided with a screw thread as shown in the illustration, but it is now made to fit into the cup B air tight by means of a cone joint 2.8 cm. long. The discharge tube itself is no longer cast into the collar A with Khotinski cement, but is blown on a platinum tube 3.5 cm. long by 1.5 cm. in diameter. This tube is soldered into the collar A. By this arrangement the gas does not come in contact with grease in the joints, and the danger of leak is considerably reduced.

Measurements in the region between λ 1850 and λ 1675 where no fiducial lines exist were made by the two slit method.[7] In the region from λ 1675 to λ 1300 direct comparison was made with the spectrum of hydrogen.

The values of λ refer to the heads of bands, and they are accurate to 0.3 of an Angström unit. In the class of the double bands marked "*d*" the wave-length given is for the stronger component. The intensities are represented on a scale of ten. The absorption of fluorite, which begins to make itself felt near the end of the spectrum, renders the relative intensities of the most refrangible bands rather uncertain. As usual, the wave-lengths and frequencies are in vacuum.

In addition to their value as standards of wave-length, the results are of some theoretical importance. Deslandres in the paper just quoted[8] has used his measurements of the carbon spectrum to test his Laws. As the spectrum under discussion seems to form a continuation of that described by Deslandres, it is interesting to see if its bands also show the numerical relations described by the earlier investigator. In making the comparison, however, it will be necessary to confine the attention to those relations which deal with the heads of the bands, for the dispersion employed does not permit of the study of the lines of which each band is composed. It must also be remembered that the region of high frequencies is not perfectly adapted to such a test, since a small error in the wave-length is magnified in relations which deal with frequencies.

The laws under discussion are two in number: first, that a group of bands may be broken up into sets of series such that the differences in frequency of the heads of the bands in any one series form an arithmetical progression; second, that all the series are similarly constructed. The first rule may obviously be stated in another way, — the second differences of the frequencies of the heads of the bands in any one series are constant.

[7] See note 2.

[8] Loc. cit.

TABLE I.

Fourth Group.

Series	Deslandres.				Lyman.											
	IV		V		VI		VII		VIII		IX		X		XI	
	N.	2nd Diffs.	N.	2nd Diffs.	N.	2nd Diffs.	N.	2nd Diffs.	N.	2nd Diffs.	N.	2nd Diffs.	N.	2nd Diffs.	N.	2nd Diffs.
	46981	. .	49821 [1]													
	46499	—2	49349 [1]	5	52247											
	46019	10	48872	28	51773	27										
	45529	22	48367	15	51272	12										
	45017	9	47847	10	50759	20	54309									
	44496	2	47317	—3	50226	6	53775	7								
	43973	13	46790	19	49687	10	53234	6								
	43437	. .	46244	11	49138	. .	52687	8	56341							
	. .	. .	45687	. .	. .	. .	52132	. .	55785	11						
	. .	. .	. .	. .	. .	. .	. .	. .	55218	9	58404					
	. .	. .	. .	. .	. .	. .	. .	. .	54642	. .	57820	5				
	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	57231	16				
	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	[56626]	2				
	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	56019	7				
	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	55405	17	58641			
	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	54774	. .	58008	19		
	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	57356	. .	61338	
	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	60672	
	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	59999	
	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	(57337)	
Av. 2nd Diff.	. .	9	. .	13	. .	15	. .	7	. .	10	. .	9	. .	19	. .	7

[1] From the writer's measurements.

Deslandres has analysed his Fourth Group into five series, characterized by small and not very regular second differences. The writer has

TABLE II.

FOURTH GROUP.

DESLANDRES.			LYMAN.					
First Differences.			First Differences.					
Series	IV	V	VI	VII	VIII	IX	X	XI
	482	472						
	480	477	474					
	490	505	501					
	512	520	513					
	521	530	533	534				
	523	527	539	541				
	536	546	549	547				
	. .	557	. .	555	556			
	. .	. .	. .	. .	567			
	. .	. .	. .	. .	576	584		
	. .	. .	. .	. .	. .	589		
	. .	. .	. .	. .	. .	605		
	. .	. .	. .	. .	. .	607		
	. .	. .	. .	. .	. .	614		
	. .	. .	. .	. .	. .	631	633	
	. .	. .	. .	. .	. .	. .	652	
	. .	. .	. .	. .	. .	. .	. .	666
	. .	. .	. .	. .	. .	. .	. .	673

been able to follow the arrangement into the region between λ 2000 and λ 1600 and has added seven new series of the same type. Table I.

shows these new members. They are numbered from VI. to XI.; series IV. and V. of Deslandres' are included in the table for the sake of comparison. The first two bands in the fifth series were measured by the writer. When it is remembered that the errors of observation make the fifth place in the frequencies very doubtful, it will be seen that the law of constant second differences is fairly well obeyed.

TABLE III.

FIFTH GROUP.

Series	1		2		3		4		5		6	
	N.	2nd Diffs.	N.	2nd Diffs.	N.	2nd Diffs.	N.	2nd Diffs.	N.	2nd Diffs.	N.	2nd Diffs.
	65772	. .	66366	. .	67527	. .	69266	. .	70852	. .	71649	
	65531	109	65976	124	67204	116	68852	118	70721	118	71372	123
	65181	110	65462	106	66765	132	68320	129	70472	102	70972	100
	64721	130	64842	. .	66194	. .	67659	. .	70121	113	70472	
	64131	109	. .	. .	. .	. .	. .	. .	69657	84		
	63432	131	. .	. .	. .	. .	. .	. .	69109			
	62602											
Av. 2d Diffs.	. .	118	. .	115	. .	124	. .	123	. .	104	. .	112

Table II., which gives the first differences for each series, is arranged to show the similarity which exists among the members. It will be observed that the second rule is obeyed, for the series resemble each other. An exact similarity is not demanded by the rule as has been recently pointed out by Deslandres himself.[9] The arrangement of the series, however, does not permit of the "second progression"[10] mentioned by Olmsted and others.

In addition to the series VI. to XI. there appear to exist two others, in the region near λ 1800. These show larger second differences than the first type. They have not been included in the tables.

[9] Comptes Rendus, 1904, **138**, 317.

[10] Comptes Rendus, 1902, **134**, 748; Zeits. f. Wiss. Photographie, 1906; **4**, 255.

TABLE IV.

λ.	I.	N.	λ.	I.	N.
1335.0	1	74,906	1615.1	2	61,916
1339.0	1	74,683	1623.4	1	61,599
1343.0	1	74,460	1629.6	3	61,365
1353.6	1	73,877	1630.3	6	61,338
1356.1	2	73,741	1648.2	5	60,672
1361.3	2	73,459	1653.3	4	60,485
1368.0	1	73,099	1666.7	1	59,999
1371.8	2	72,897	1669.9	6	59,884
1374.1	2	72,775	1685.3	1	59,337
1378.1	2	72,564	1688.5	1	59,224
1384.4	1	72,233	1698.8	1	58,865
1386.4	1	72,129	1705.3	6	58,641
1392.2	1	71,829	1712.2	7	58,404
1395.7	2	71,649	1723.9	6	58,008
1401.1	2	71,372	1729.5	8 *d*	57,820
1404.0	1	71,225	1743.5	3	57,356
1405.5	1	71,149	1747.3	7	57,231
1409.0	2	70,972	1774.9	8 *d*	56,341
1411.4	1	70,852	1785.1	6	56,019
1414.0	1	70,721	1792.6	10 *d*	55,785
1419.0	2	70,472	1801.9	2	55,497
1426.1	3	70,121	1804.9	8	55,405
1435.6	2	69,657	1811.0	10 *d*	55,218
1438.7	1	69,507	1825.7	7	54,774
1443.7	1	69,266	1830.1	9	54,642
1447.0	1	69,109	1837.2	1	54,431
1452.4	3	68,852	1841.3	8	54,309
1463.7	3	68,320	1846.7	2	54,151
1473.0	1	67,889	1849.4	4	54,072
1475.4	1	67,778	1859.6	10 *d*	53,775
1478.0	2	67,659	1870.3	3	53,467
1480.9	2	67,527	1878.5	10 *d*	53,234
1488.0	2	67,204	1891.2	6	52,876
1493.8	3	66,943	1898.0	10	52,687
1497.8	3	66,765	1914.0	1	52,247
1506.8	2	66,366	1918.2	7	52,132
1510.7	2	66,194	1931.5	6	51,773
1515.7	3	65,976	1933.6	2	51,717
1520.4	1	65,772	1950.4	4	51,272
1526.0	2	65,531	1951.7	5	51,237
1527.6	3	65,462	1953.0	5	51,203
1534.2	2	65,181	1970.1	8	50,759
1542.2	5	64,842	1991.0	1	50,226
1545.1	3	64,721	2007.2	5	49,821
1559.3	5	64,131	2012.6	8	49,687
1576.5	4	63,432	2026.4	7	49,349
1596.1	1	62,653	2031.7	1	49,220
1597.4	3	62,602	2035.1	4	49,138
1603.3	1	62,371	2047.0	8	48,852
1611.7	3	62,046	2068.4	8	48,347

On the more refrangible side of λ 1600 matters are not very satisfactory. The bands must be arranged into series showing very large second differences which are only approximately constant. These series, which are numbered from 1 to 7 go to make up the Fifth Group. Their frequencies together with the second differences are given in Table III. No attempt has been made to adopt an arrangement which would show the similarity between the members of the group. In fact these series fall in with the second rule only to a limited degree; 1 and 5 resemble each other, as do 2 and 6, and 3 and 7, but the relations are not exact.

The writer makes no claim that the arrangements given in this Fifth Group are the best possible, they are only the most obvious.

The spectrum contains a great many bands which are either too feeble to measure or whose positions are made uncertain by the tails of stronger bands; if these could be included in the series a better system would probably result.

It is to be remembered that although relations similar to Deslandres' laws have been proved to hold within the limit of error of observation for the distribution of lines within a band,[11] no such accuracy of agreement has been found when the laws of the distribution of the heads of the bands themselves have been tested. In fact, the rule of constant second differences as applied to the heads of bands must be looked upon as a first approximation only. The work which has just been described indicates that the approximation holds even in the region of extremely short wave-lengths.

In conclusion the writer wishes to point out that the important results of the investigation are the values of the wave-lengths contained in Table IV.

Jefferson Physical Laboratory,
Cambridge, Mass.,
December, 1909.

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[11] v. Carlheim-Gyllensköld, K. Svensk. Vetenskaps-Akad., Handl., 1907, **42**, No. 8.